ROTARY ENGINE

This is a continuation-in-part of U.S. Patent Application Serial No. 10/441,807 filed on 5/19/2003, the content of which is relied upon and incorporated herein by reference in its entirety, and the benefit of priority under 35 U.S.C. § 120 is hereby claimed.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The invention relates to an internal combustion engine, and more specifically to a rotary internal combustion engine.

TECHNICAL BACKGROUND

[0002] The internal combustion engine has been at the center of industrial evolution for the last century. One of the most dramatic aspects of this evolution has been the automobile, which has helped to shape and transform a culture. Yet for all the dramatic technological progress over the last 100 years, the internal combustion engine, and particularly the reciprocating internal combustion engine, has not substantially changed during that period. Although significant improvements have been made in the design and construction of internal combustion engines, the reciprocating piston internal combustion engine that dominates the automotive industry remains notoriously energy inefficient, commanding only about a 24% overall efficiency.

[0003] Rotary engines overcome some of the problems inherent in reciprocating internal combustion engines. The Wankel rotary engine is the most well-known of the rotary engines, having enjoyed a small amount of commercial success in certain automobiles. The engine has approximately 48% fewer moving parts than an equivalent reciprocating piston engine, with about one third the size and weight. One advantage of the Wankel rotary engine over reciprocating piston internal combustion engines is a higher RPM than reciprocating piston engines since the reciprocating motion of the pistons is eliminated. However, the Wankel engine also tends to have low torque at high speeds, thereby resulting in increased fuel consumption.

[0004] Prior art rotary engines have attempted to address many of the shortcomings of both the reciprocating piston internal combustion engine and the Wankel rotary engine. Prior art rotary engines have, for example, used a rotating valve which

compression region of the engine and the rotating combustion chamber as the piston advances toward the valve in order to minimizes sharp pressure changes in the engine. However, such prior art rotary engines fail to provide for a continuous discharge of the expanding combustion gases from the combustion chamber as the valve and combustion chamber rotate. Other prior art rotary engines disclose rotating valves having internal combustion chambers, and include passages for equalizing pressure between the annular region surrounding the main rotor and the combustion chamber. However, the passage within these rotary engines are narrowly constructed, and provide a limited opportunity to deliver combustion gases to the annular region.

Summary

[0005] It is to be understood that both the foregoing general description and the following detailed description present embodiments of the invention, and are intended to provide an overview, or framework, for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principles and operations of the invention.

[0006] In one aspect of the invention, the rotary engine includes a housing having a first and second intersecting cavity disposed therein. Each of the first and second cavities have cylindrical wall surfaces. A rotor is rotatably mounted in the first cavity, and the housing and the rotor define an annular chamber disposed therebetween. The rotor includes a piston extending from the rotor into the annular chamber. A first valve, rotatably mounted in the second cavity, has a circumference and includes a recess sized to receive the piston during a rotation of the rotor. The rotary engine also includes at least one passage including an open portion formed in the cylindrical wall surface of the second cavity and an enclosed portion enclosed by the housing along a length of the enclosed portion, the open portion including a leading end and a trailing end with respect to a direction of rotation of the first valve and which open portion extends for at least about 20 degrees around a circumference of the cylindrical wall surface of the second cavity, and wherein the enclosed portion connects the open portion to the annular chamber downstream of the second cavity relative to a direction of rotation of the rotor.

[0007] The passage, the open portion of which extends around a portion of the circumference of the valve cavity and the enclosed portion which further connects the open portion with the annular cavity, advantageously collects expanding combustion gases from the valve recess (in which combustion was initiated) and carries the expanding combustion gases from the valve recess to the annular chamber behind the passing piston through a portion of the rotation of the valve, thus providing for efficient fuel utilization and reduced emission of undesirable waste products through more complete combustion of the fuel.

[0008] Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled

in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0009] It is to be understood that both the foregoing general description and the following detailed description present embodiments of the invention, and are intended to provide an overview, or framework, for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principles and operations of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a view of a first embodiment of the rotary engine according to the present invention.

[0011] FIG. 2 is a detail view of a piston fitted with a compression seal.

[0012] FIG. 3 is a detail view of a combustion valve and combustion valve cavity showing multiple fuel and ignition ports.

[0013] FIG. 4 is a detail view of a combustion valve and combustion valve cavity showing the relative locations of the leading and trailing ends of a passage in the wall surface of the combustion valve cavity.

[0014] FIG. 5 is a perspective view of a combustion valve cavity showing the location and arrangement of multiple passages.

[0015] FIG. 6 is a detail view of a combustion valve cavity and combustion valve showing the arrangement of multiple passages.

[0016] FIG. 7 is a detail view of the inside surface of the rotor cavity showing the relative location where the passages open into the annular chamber.

[0017] FIG. 8 is a view of the rotary engine of FIG. 1 as a first piston begins compressing air at a front surface and drawing in fresh air behind it.

[0018] FIG. 9 is a view of the rotary engine of FIG. 1 showing the pistons being received into the valve recesses.

[0019] FIG. 10 is a detail view of a combustion valve showing a piston being received by a valve recess.

[0020] FIG. 11 is a view of the rotary engine of FIG. 1 showing the valves and pistons at top dead center position.

[0021] FIG. 12 is a detail view of a combustion valve showing the relative positions between a piston, a rotating combustion valve and a passage as before combustion gases begin to be carried from the combustion valve to the annular chamber by the passage.

[0022] FIG. 13 is a detail view of a combustion valve showing the relative positions between a piston, a rotating combustion valve and a passage as combustion gases begin to be carried from the combustion valve to the annular chamber by the passage.

[0023] FIG. 14 is a view of a second embodiment of the rotary engine according to the present invention.

DETAILED DESCRIPTION

[0024] In the following, preferred embodiments of the rotary engine in accordance with the present invention will be explained in detail with reference to the drawings. In the explanation of the drawings, constituents identical to each other will be referred to with numerals or letters identical to each other, without repeating their overlapping descriptions. Also, ratios of sizes in the drawings do not always coincide with those explained.

[0025] In a first embodiment of the invention, shown in FIG. 1, rotary engine **10** includes a housing **12** defining a main cylindrical cavity **14**. A rotor **16**, rigidly and coaxially attached to a drive shaft (not shown), is rotatably and coaxially mounted within main cavity **14**. The rotor **16** and the housing **12** define an annular chamber **18** disposed therebetween. Main cavity **14** will hereinafter be referred to as rotor cavity **14**.

[0026] Rotor **16** includes two pistons **20a** and **20b** extending from rotor **16** into annular chamber **18**. Pistons **20a** and **20b** may be rigidly attached to the periphery of rotor **16**, for example by suitable fasteners, such as bolts, or by welding, or pistons **20a** and **20b** and rotor **16** may be formed from a homogeneous material by casting or milling, for example. Preferably, rotor **16** includes slots **22a** and **22b** in which pistons **20a** and **20b** are disposed. Preferably, pistons **20a** and **20b** are rigidly mounted in slots **22a** and **22b**, more preferably pistons **20a** and **20b** are slidably disposed in slots **22a** and **22b**, respectively. Preferably, slots **22a** and **22b** each include an extension element **24**, wherein the extension of pistons **20a** and **20b** into annular chamber **18** may be varied by extension element **24** to adjust the clearance between pistons **20a** and **20b** and the wall surface of rotor cavity **14** (which is also the outer wall surface of annular chamber **18**). Extension element **24** may be, for example, a jack screw. Preferably, pistons **20a** and **20b** are in sliding contact with the wall surface of rotor cavity **14**. As depicted in FIG. 2, pistons **20a** and **20b** preferably include slots **26a** and **26b**, located at the apex of pistons **20a** and **20b,** in which compression seals **28a** and **28b** are disposed. FIG. 2 illustrates piston **20a** with slot **26a** and seal **28a**. The reference numbers in parenthesis represent a similar configuration for piston **20b**.

[0027] Referring again to FIG. 1, housing **12** further defines two cylindrical cavities **30a** and **30b** disposed adjacent to, and intersecting with, rotor cavity **14**. Cylindrical

valves **32a** and **32b** are rotatably and coaxially mounted within the two cavities **30a** and **30b,** respectively. It should be noted that for the purposes of illustration only, an appreciable gap is seen in FIG. 1 between the wall surfaces of cavities **30a** and **30b**, and the outside cylindrical surface of their respective valves **32a** and **32b**. Preferably, the fit between the walls of cavities **30a** and **30b**, and the outside cylindrical surface of their respective valves **32a** and **32b** is sufficiently close to minimize leakage of gases around the valves and into annular chamber **18**.

[0028] Cylindrical valves **32a** and **32b** are positioned relative to rotor **16** such that the outside cylindrical surfaces of valves **32a** and **32b** are in close proximity to the corresponding outside cylindrical surface of rotor **16** in order to minimize any leakage of gases between the valves **32a** and **32b** and rotor **16**. Without such close proximity, the leakage of gases between valves **32a** and **32b** and rotor **16** would result in a reduction in power output from the engine.

[0029] Each valve **32a** and **32b** includes a recess **34a** and **34b** formed in the outside cylindrical surface of the valves, respectively, each of the recesses **34a** and **34b** being sized to receive pistons **20a** and **20b** during a rotation of rotor **16**. That is, as each piston moves past a valve, the piston is inserted into the valve recess, thus allowing the piston to traverse the valve. For the purpose of further discussion, valve **32a** defines a combustion valve and valve **32b** defines an intake/exhaust valve. Cavities **30a** and **30b** will hereinafter be referred to as combustion valve cavity **30a** and intake/exhaust valve cavity **30b**.

[0030] Rotor **16**, combustion valve **32a** and intake/exhaust valve **32b** are connected through conventional mechanical linkages (not shown), such as shafts and gears, so that valves **32a** and **32b** rotate in a direction opposite that of rotor **16**, and are synchronized therewith such that, as each piston traverses a valve, the piston is received into a recess. Rotor **16** is hereinafter assumed to rotate in a clockwise direction, while valves **32a** and **32b** are assumed to rotate in a counterclockwise direction. However, rotary engine **10** could easily be designed wherein rotor **16** rotates in a counterclockwise direction and valves **32a** and **32b** rotate in a clockwise direction. Valves **32a** and **32b** also each preferably have a diameter one half the diameter of rotor **16**, and preferably rotate two full cycles (720 degrees) for every one full cycle of rotation (360 degrees) of rotor **16**.

[0031] Housing **12** further includes an air intake port **36** for the intake of air into annular chamber **18**, and an exhaust port **38** for the discharge of combustion gases from annular chamber **18**. Intake port **36** and exhaust port **38** are positioned near intake/exhaust valve **32b**. Preferably, intake port **36** and exhaust port **38** are partially overlapped by intake/exhaust valve **32b** during at least a portion of the rotation of intake/exhaust valve **32b**. During at least a portion of the rotation of intake/exhaust valve **32b**, recess **34b** is preferably positioned so as to provide an increased flow of combustion gases discharged through exhaust port **38**, and air brought in through intake port **36**. Thus intake/exhaust valve **32b** varies the flow of intake air and combustion gases into and out of annular chamber **18**, respectively.

[0032] The positioning of intake port **36** and exhaust port **38** near intake/exhaust valve **32b** maximizes the working distance of each piston undergoing a combustion event. Maximizing the distance a piston travels from the time ignition of the fuel occurs to the time the piston passes exhaust port **38**, maximizes the time during which the expanding combustion gases are acting upon the rearward surface of the piston to drive the piston forward, while the forward surface of the piston simultaneously forces the combustion gases from the previous combustion event from annular chamber **18** through exhaust port **38**. Similarly, the intake of fresh air through intake port **36** is maximized by extending the distance between intake port **36** and the point at which valve **20a** and rotor **16** are at their closest proximity. Thus, more energy may be extracted from the expanding combustion gases, and ventilation of the engine is optimized.

[0033] Housing **12** also includes at least one fuel injection port **40** located in housing **12** and connecting with combustion valve cavity **30a** such that an end face of combustion valve **32a** completely covers fuel injection port **40** during at least a portion of the rotation of combustion valve **32a**. During another portion of the rotation of combustion valve **32a** fuel injection port **40** is uncovered by recess **34a**, allowing fuel to be injected directly into recess **34a**. Fuel may be injected, for example, by a conventional automotive fuel injector. In addition to fuel injection port **40**, at least one ignition port **42** is also located in housing **12** and connecting with combustion valve cavity **30a** such that an end face of combustion valve **32a** completely covers ignition port **42** during at least a portion of the rotation of combustion valve **32a**. That is, both fuel injection port **40** and ignition port 42 are

located adjacent to an end face of combustion valve **32a**. Preferably, both fuel injection port **40** and ignition port **42** are both uncovered during the same portion of the rotation of combustion valve **32a**. Ignition port **42** may be fitted with a conventional ignition device, such as, for example, a spark plug or, depending upon the compression ratio in the combustion chamber, a glow plug. In some instances, for example when compression ratios exceed about 20:1, ignition may occur spontaneously during injection of the fuel as a result of heat generated during the compression of air by the pistons, in which case an ignition device may not be necessary.

[0034] It should be noted that, although FIG. 1 indicates fuel injection port **40** and ignition port **42** located on a single side of housing **12**, multiple fuel injection ports and ignition ports may advantageously be employed. For example, a fuel injection port may be located on either side of housing **12**, both fuel injection ports connecting to combustion valve cavity **30a** at opposing locations so that fuel may be injected into recess **34a** simultaneously from both ends of recess **34a**. That is, a fuel injection port **40** may be connected with combustion valve cavity **30a** adjacent one end of combustion valve **32a**, relative to the axis of rotation of combustion valve **32a**, while another fuel injection port **42** may be connected with combustion valve cavity **30a** adjacent the opposing end of combustion valve **32a**. Preferably, the opposing fuel injection ports are positioned at about the same radial position so that fuel may be injected into recess **34a** from both ports at the same time. An ignition port **42** may be similarly positioned on either side of housing **12** and connecting with combustion valve cavity **30a** at generally opposing locations so that the ignition devices can be simultaneously utilized to ignite the fuel from opposite ends of recess **34a**.

[0035] In addition, where a plurality of fuel injection ports **40** are used, fuel injection ports **40** may be spaced at predetermined points about the axis of rotation of combustion valve **32a** and "below" combustion valve **32a** (that is, such that each fuel injection port is covered by an end face of combustion valve **32a** during at least a portion of the rotation of combustion valve **32a**) so that, as combustion valve **32a** , and recess **34a**, rotate, additional fuel may be injected into recess **34a** as recess **34a** uncovers each successive fuel injection port and additional fuel is injected into recess **34a** to prolong the combustion process and provide additional combustion gases. Fig. 3 is a detail view of combustion valve **32a** and combustion valve cavity **30a** showing

multiple fuel injection ports **40** located at an end of combustion valve **32a**. The dashed lines indicating combustion ports **40** show that the plurality of fuel injection ports are covered by an end face of combustion valve **32a** in the rotary position indicated. A plurality of ignition devices may also be used to sustain the combustion process, represented by the additional ignition ports **42** shown in FIG. 3.

[0036] Again referring to FIG. 1, at least one passage **44** extends along a portion of the circumference of the wall surface of combustion valve cavity **30a**, through the interior of housing **12**, and opens into annular cavity **18** through the wall surface of rotor cavity **14**. The passage **44** includes an open portion **46** and an enclosed portion **48**. The open portion **46** of passage **44** is positioned around a portion of the circumference of the wall surface of combustion valve cavity **30a** and is open to combustion valve cavity **30a** along the length of open portion **46**. Open portion **46** of passage **44** includes a trailing end **50** and a leading end **52** relative to the direction of rotation of combustion valve **32a**. Preferably, the open portion **46** of passage **44** extends at least about 20 degrees around the circumference of combustion valve cavity **30a**, more preferably for at least about 45 degrees, still more preferably for about at least 90 degrees, and most preferably for at least about 180 degrees. As shown in FIG. 4, open portion **46** of passage **44** terminates at trailing end **50** a distance **56** from the intersection **58** between combustion valve cavity **30a** and rotor cavity **14** on the downstream side of combustion valve cavity **30a**, relative to the direction of rotation of combustion valve **32a**. Preferably, distance **56** is greater than the distance **60** across the entrance, or mouth, of recess **34a** to prevent recess **34a** from serving as a pressure short circuit between the region of annular chamber **18** on one side of combustion valve **32a** and the region of annular chamber **18** on the opposite side of combustion valve **32a**. Leading end **52** of the open portion **46** of passage **44** is preferably located a distance **62** from intersection **64** of rotor cavity **14** and combustion valve cavity **30a**. Preferably, distance **62** is greater than distance **60**, i.e. greater than the width of the mouth of recess **34a**, to prevent combustion gases from being carried to annular chamber **28** prematurely, ahead of advancing piston **20a**.

[0037] Still referring to FIG. 4, enclosed portion **48** of passage **44** extends from leading end **52** of open portion **46** through the interior of housing **12**, and opens into annular chamber **18** through the cylindrical wall surface of rotor cavity **14**

downstream of combustion valve cavity **30a** relative to the direction of rotation of rotor **16**. Enclosed portion **48** of passage **52** is enclosed by housing **12** along the length of enclosed portion **48**.

[0038] Preferably, a plurality of passages **44** are disposed around at least a portion of the circumference of combustion valve cavity **30a**. FIGS. 5-7 show three additional views of multiple passages **44**. For illustration purposes, a total of three passages are shown in FIGS. 5-7. However, the number of passages is dependent upon, inter alia, the length of combustion valve **32a**, i.e. the distance in a direction parallel to the axis of rotation of valve **32a**. The longer the length of valve **32a**, the more passages that are needed for carrying combustion gases from recess **34a** in rotating combustion valve **32a** to annular chamber **18**. FIG. 5 is a detail view of the wall surface of combustion valve cavity **30a** and a portion of the wall surface of rotor cavity **14**. Visible in FIG. 5 are the open portions **46** of passages **44** located along the wall of combustion valve cavity **30a**, and a view of the locations on the wall surface of rotor cavity **14** where the enclosed portions **48** of passages **44** open into annular chamber **18**. FIG. 6 is a second view of combustion valve cavity **30a** showing combustion valve **32a** and the open portions **46** of passages **44** along a portion of the wall surface of combustion valve cavity **30a**. It should be noted that, although the passages illustrated in FIG. 6 have a generally rounded shape, the passages may have other geometric shapes as may be needed for engine performance or machineability, such as, for example, rectangular. FIG. 7 is a detail view of the wall of rotor cavity **14** showing the location where the enclosed portions **48** of passages **44** open into annular chamber **18**. The dashed lines in FIG. 7 indicate where the enclosed portions **48** of passages **44** extend through the interior of housing **12**, from the wall surface of annular chamber **18** toward combustion valve cavity **30a**.

[0039] The following describes the operation of rotary engine **10**. FIGS. 8, 9 and 11 show rotor **16** in three different rotary positions. As rotor **16** rotates in a clockwise direction through annular chamber **18**, valves **32a** and **32b** are simultaneously rotating in a counterclockwise direction at a radial velocity such that the surface speed at the outside cylindrical surface of valves **32a** and **32b** are the same as the surface speed at the outside cylindrical surface of rotor **16**. Valves **32a** and **32b** preferably complete two full (360 degree) rotations for each complete rotation of rotor **16**. Valves **32a** and **32b** are preferably one half the diameter of rotor **16**. Optionally, valves **32a** and **32b**

may also be formed with multiple recesses, wherein the diameter of valves **32a** and **32b** may be adjusted accordingly. For example, in the case where valves **32a** and **32b** have two recesses each, valves **32a** and **32b** preferably have the same diameter as rotor **16** and valves **32a** and **32b** preferably complete one full revolution for each full revolution of rotor **16**.

[0040] As shown in FIG. 8, as piston **20a** leaves intake/exhaust valve **32b**, intake/exhaust valve **32b** is rotating into a position in which recess **34b** passes over intake port **36**, allowing an increased flow of air into annular chamber **18** behind piston **20a** through intake port **36**. At the same time, piston **20a** is compressing air ahead of the forward face of piston **20a** which was previously drawn into annular chamber **18** through intake port **36** by piston **20b**. Turning to FIG. 9, as piston **20a** approaches combustion valve **32a**, combustion valve **32a** is rotating into a position such that piston **20a** is received into recess **34a**, therefore allowing piston **20a** to traverse valve **32a**. FIG. 10 shows a detail view of piston **20a** being received into recess **34a**. Recess **34a** is sized to ensure that there is sliding contact between piston **20a** and recess **34a** at a minimum of two points **66** and **68** on piston **20a** while piston **20a** is cooperating with recess **34a**. Points **66** and **68** are located on opposing sides of piston **20a**, thus sealing recess **34a** from annular chamber **18**. The exact location of points **66** and **68** may vary as rotor **16** and combustion valve **32a** rotate. The excess space between the portion of piston **20a** received into recess **34a** and combustion valve **32a** encompassing and defining recess **34a** forms a closed combustion chamber **70** within recess **34a** during the time that piston **20a** is cooperating with valve **32a**. The size and shape of recess **34a**, and therefore combustion chamber **70**, may be varied depending upon such design-dependent variables as fuel choice, compression ratio, piston size, engine power output, and so forth.

[0041] Referring now to FIG. 11, as piston **20a** traverses valve **32a** it approaches a top dead center position. Top dead center is defined as the position wherein pistons **20a** and **32b**, and recesses **34a** and **34b** lie symmetrically on a line extending from the axis of rotation of combustion valve **32a** to the axis of rotation of intake/exhaust valve **32b**. At a position of top dead center, piston **20a** (or piston **20b**) is at a point of maximum insertion into recess **34a** (or recess **34b**). The relative position of pistons and valves at top dead center is illustrated in FIG. 11. As combustion valve **32a** approaches the top dead center position, fuel injection port **40** is uncovered by recess

34a and fuel is injected into combustion chamber **70** formed between piston **20a** and valve **32a** in recess **34a**.

[0042] During a period of time in which ignition port **42** is uncovered and piston **20a** is received into recess **34a**, the ignition device in ignition port **42** ignites the fuel in combustion chamber **70**. Thus ignition is initiated entirely within the confines of combustion chamber **70** in recess **34a**, i.e. within the circumference of combustion valve **32a**. The timing of the fuel ignition, that is, for example, the firing of a spark plug, is dependent upon a variety of factors, including engine load, altitude, engine speed, etc., and is controlled by conventional methods. For example, a distributor may be used to time the ignition. Alternatively, ignition may be timed by a computing device which uses data from a variety of sensors to optimize ignition. Sensed parameters may include engine speed, air temperature, exhaust gas oxygen content, and other parameters as may be required to optimize ignition.

[0043] Expanding gases from the combustion of the fuel act against piston **20a**, driving rotor **16** in a clockwise rotation. As combustion valve **32a** rotates, piston **20a** leaves recess **34a** and the expanding combustion gases enter annular chamber **18** behind piston **20a**, continuing to force piston **20a** in a clockwise direction through annular chamber **18**. As combustion valve **32a** rotates further in a counterclockwise direction, the opening into recess **34a** rotates from annular chamber **18** into combustion valve cavity **30a**, momentarily closing off recess **34a**, as depicted in FIG. 12. As shown in FIG. 13, recess **34a** in rotating combustion valve **32a** opens into passage **44** as piston **20a** sweeps past the location on the wall surface of rotor cavity **14** where the enclosed portion **48** of passage **44** opens into annular chamber **18**. As valve **32a** rotates, and while recess **34a** is adjacent to the open portion **46** of passage **44**, combustion gases expanding from recess **34a** are carried by passage **44** to annular chamber **18** as piston **20a** passes the opening of passage **44** positioned on the wall surface of rotor cavity **14**, thus ensuring that the expanding combustion gases are carried from recess **34a** in combustion valve **32a** to annular chamber **18** behind piston **32a**. Without proper positioning of the at least one passage **44**, combustion gases may otherwise be carried to a location ahead of advancing piston **20a**, thereby reducing the efficiency of the engine.

[0044] The operation of rotary engine **10** continues in an identical manner, now with focus on piston **20b**. As rotor **16** continues to rotate in a clockwise direction, piston **20b** approaches combustion valve **32a**. Piston **20b** compresses the air in annular chamber **18** previously drawn in through intake port **36** by piston **20a** while simultaneously drawing in fresh air through intake port **36** behind piston **20b**. As piston **20b** approaches combustion valve **32a**, piston **20b** is received into recess **34a**, therefore allowing piston **20b** to traverse valve **32a**. As piston **20b** rotates through valve **32a** it approaches a top dead center position. The excess space between the portion of piston **20b** received into recess **34a** and combustion valve **32a** encompassing and defining recess **34a** again defines combustion chamber **70**. Also, as valve **32a** nears the top dead center position, recess **34a** uncovers fuel injection port **40** and fuel is injected into recess **34a**.

[0045] As with the ignition event involving piston **20a**, during a period of time in which ignition port **42** is uncovered and piston **20b** is received by recess **34a**, the ignition device located in ignition port **42** ignites the fuel. Ignition timing may be controlled in a manner as previously described. Expanding gases from the combustion of the fuel act against piston **20b**, driving rotor **16** in a clockwise rotation. As combustion valve **32a** rotates in a counterclockwise direction, combustion gases expanding from recess **34a** continue to expand into annular chamber **18** behind piston **20b** through passage **44**, driving piston **20b** forward in a clockwise rotation through annular chamber **18**. As piston **20b** nears intake exhaust valve **32b**, intake/exhaust valve **32b** rotates to a position where recess **34b** provides for increased flow through exhaust port **38**, and piston **20b** simultaneously forces the remaining combustion gases forward of piston **20b**, which resulted from the previously described combustion event of piston **20a**, out through exhaust port **38**.

[0046] As can readily be appreciated, rotary engine **10** advantageously has two ignition, or combustion events (power strokes) during each 360 degree rotation of rotor **16**, with each piston participating in a power stroke. That is, as each of the pistons passes through combustion valve **32a**, a combustion event occurs. The combustion gases resulting from the combustion event are directed behind the piston, driving rotor **16** in a clockwise rotation until the combustion gases are discharged from the engine through exhaust port **38**.

[0047] As will be apparent to those skilled in the art, rotary engine **10** may include additional pistons and valves. That is, pistons and valves may be doubled, the total number of valves being an even number, and the valves being equally divided between combustion valves and intake/exhaust valves, moving from a two-piston two-valve engine to a four-piston four-valve engine to an eight-piston eight-valve engine and so forth. Moreover, as intake/exhaust valves are added, a requisite number of intake ports and exhaust ports are also added, one intake port and one exhaust port for each intake/exhaust valve. In the direction of rotation of rotor **16**, each combustion valve is followed by an intake/exhaust valve.

[0048] In a preferred embodiment of the invention, rotary engine **110**, shown in FIG. **14**, is similar to rotary engine **10** of the previous embodiment except that two pistons and two valves have been added, for a total of four pistons **120a**, **120b**, **120c** and **120d**, and four combustion valve cavities **130a**, **130b**, **130c**, and **130d** in which are mounted four valves; combustion valves **132a** and **132c**, and intake/exhaust valves **132b** and **132d**. Preferably, pistons **120a** and **120b**, **120c** and **120d** are slidably disposed in rotor **116**. The four valves **132a**, **132b**, **132c**, and **132d** each include at least one recess **134a**, **134b**, **134c**, and **134d**, respectively, to allow passage of pistons **120a** and **120b**, **120c** past valves **132a-132d** during rotation of rotor **116**. In the manner described for rotary engine **10**, recesses **134a** and **134c** function as combustion chambers when receiving a piston. Also as in the previous embodiment, the diameter of the valves, and the number of recesses in each valve is dependent upon the number of pistons and the constraints that a) the surface speed of each valve matches the surface speed of the rotor and b) the number of valves is equal to the number of pistons. For the four-piston, four-valve engine of the present embodiment, for example, each valve may include two recesses, in which case each valve would have a diameter one half the diameter of rotor **116**. On the other hand, for the case in which each valve is comprised of four recesses, each valve will have a diameter equal to the diameter of rotor **116**. The number of valves or pistons, the diameter of the valves and the number of recesses in each valve can be related through the expression

$$D = R/P \qquad [1]$$

where D is the diameter of the valves expressed as a fraction of the diameter of the rotor, R is the number of recesses in each valve and P is the number of pistons (or valves).

[0049] Rotary engine **110** further includes intake port **136b** and exhaust port **138b**, and intake port **136d** and exhaust port **138d** located near intake/exhaust valves **132b** and **132d**, respectively. Preferably, intake ports **136b** and **136d**, and exhaust ports **138b** and **138d** are partially overlapped by intake exhaust valves **132b** and **132d**, respectively, and valves **132b** and **132d** vary the flow of gases through each respective port.

[0050] Rotary engine **110** also includes at least two fuel injection ports **140a** and **140c**, at least two ignition ports **142a** and **142c**, and passages **144a** and **144c** extending along a portion of the circumference of the wall of combustion valve cavities **130a** and **130c**, respectively, and further extending through housing **112** and opening into annular chamber **118** through the cylindrical wall surface of rotor cavity **114** downstream of combustion valves **132a** and **132c** (relative to the direction of rotation of rotor **116**), respectively. The location and function of the passages **144a** and **144c** in combustion valve cavities **130a** and **130c** follows the location and function of the at least one passage **44** of rotary engine **10** disclosed supra, with appropriate scaling.

[0051] Operation of rotary engine **110** is similar to the operation of rotary engine **10**. As piston **120a** rotates in a clockwise direction through annular chamber **118**, piston **120a** compresses air previously drawn into annular chamber **118** by piston **120d** through intake port **136d**. Simultaneously, piston **120a** is drawing in fresh air behind it through intake port **136d**. As piston **120a** approaches combustion valve **132a**, recess **134a** is rotating into a position to receive piston **120a**. Piston **120a** compresses the air forward of piston **120a** into recess **134a**. At a point in time during which piston **120a** is received into recess **134a** (and forms a combustion chamber), fuel is injected into recess **134a** through fuel injection port **140a**. Also at a point in time during which piston **120a** is received into recess **134a**, an ignition device located in ignition port **142a**, such as a spark plug, ignites the mixture of compressed air and fuel in recess **134a**. Expanding combustion gases acting against the rearward face of piston **120a** drives rotor **116** in a clockwise direction. As piston **120a** sweeps through annular chamber **118**, piston **120a** forces combustion gases in front of piston **120a** that resulted from the previous combustion event out through exhaust port **138b**. In addition, expanding combustion gases from recess **134a** in the presently described combustion event are directed through passage **144a** located in combustion valve

cavity **130a** into annular chamber **118** behind piston **120a** through openings in the wall surface of rotor cavity **114**.

[0052] At the same time the previously described combustion event is occurring, a similar combustion event is occurring between piston **120c** and combustion valve **132c**. It will therefore be appreciated by those skilled in the art that two (2) combustion events (or power strokes) occur for each 90 degrees of rotation of rotor **116**, for a total of eight (8) power strokes for each 360 degree rotation of rotor **116**. The increased number of pistons and valves, and thus the number of combustion events which occur for each 360 degree rotation of rotor **116** provides for smoother operation of the engine and more consistent torque output.

[0053] It will also be apparent that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.